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NASA PLAN FOR INTERNATIONAL CRUSTAL DYNAMICS STUDIES

**Geodynamics Program Office
Office of Space and Terrestrial Applications
NASA Headquarters
Washington, DC 20546**

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1.0 Introduction

1.1 Background

This document describes the international activities being planned as part of the NASA Geodynamics Program. As a parallel development, a U.S. national program for the application of space technology to geodynamics is to be undertaken by the U.S. Geological Survey, the National Science Foundation, the Defense Mapping Agency, the National Ocean Survey, National Geodetic Survey, and NASA. The Federal program is outlined in the referenced document of January 1979.

Here we present only those international aspects of the U.S. program being planned and carried out by NASA. It is anticipated that by 1981 the national program will have developed to the point that international activities in geodynamics being carried out by the Federal agencies will be included in an expanded version of the present document.

1.2 Rationale

Studies of the way the earth's crust is moving and deforming are critical to understanding earthquake mechanisms and to the eventual formulation of earthquake prediction methods which could save hundreds of thousands of lives annually. This same information is important to the search for new energy and mineral resources, since it contributes to the construction of models for the processes that form such deposits.

The crust of the earth is continually shifting and changing. We see these changes as relative movement of the thick and almost rigid plates that form the solid outer part of the earth, and as earthquakes when strains are built up in the plates to the point that ruptures occur. The dynamic processes that shape the earth are not uniform over the whole earth. The rates of movement of the tectonic plates, and the way they interact with one another, differ

widely. In some places, one plate is sliding past another; in others, one plate is being thrust under its neighbor, and elsewhere the plates are moving apart. A physical understanding of crustal dynamic processes cannot be limited to a single geographical area: only by observing what is happening globally can we hope to understand the dynamic processes and what causes them.

Many of the countries of the world have experienced substantial losses because of destructive earthquakes, and the prospect of prediction, and eventual control, of earthquakes is of great practical interest, not only in the United States but elsewhere among both industrialized and underdeveloped countries.

Until recently the precise measurement techniques needed to observe the small movements resulting from the powerful forces which deform the earth's crust did not exist: it is necessary to measure position over thousands of kilometers to an accuracy of a few centimeters. The technology which NASA has developed (partially through the use of space, and partially through the applications of systems and techniques developed because of our involvement in space) now makes it possible to obtain, in a reasonably short time span, meaningful measurements that can tell us what is happening to the plates at the present time.

Moreover, this technology has evolved to the point that it can be assimilated by scientists in the U.S. and other countries.

A strong international program of crustal dynamics studies based on this new technology is essential to U.S. interests, and would benefit this country in several ways:

1. We would obtain global information on tectonic processes which is not attainable in any other way, and which will help us develop prediction methods for earthquakes in the U.S., with great potential for savings of life and property.

2. We would gain from the humanitarian achievement of having developed methods to alleviate hazards which have plagued mankind in the past and will continue to do so in the future.

3. We would further demonstrate that the U.S. space effort and space technology are directed toward peaceful uses.

2.0 Facilities

The two principal space techniques presently employed by NASA for precise measurement of crustal movements are laser ranging and very long baseline interferometry (VLBI). In the former, laser systems are used to range to satellites in earth orbit. Twelve artificial satellites are now in orbit equipped with cube corner retroreflectors, and four retroreflector systems were placed on the Moon by the Apollo astronauts and the unmanned Soviet Luna missions. In VLBI, two or more radio telescopes are used to receive and record radio noise signals from very distant extragalactic sources (quasars). Such radio telescopes exist in NASA data acquisition facilities and radio astronomy observatories in many parts of the world.

Both these types of systems can be either permanently located at an observatory site, or mounted in automotive vehicles capable of moving between observing sites.

2.1 Fixed Observatories

Fixed laser ranging stations now exist in several countries. Lunar ranging systems are in operation or under development in the United States, France, West Germany, Australia, Japan, and the USSR. Satellite laser systems are under development or in operation in the United States, USSR, France, Switzerland, West Germany, the United Kingdom, the Netherlands, Greece, and Japan. In addition, the U.S. maintains (through the Smithsonian Astrophysical Observatory) satellite laser ranging facilities in Brazil, Peru, and Australia.

These laser systems are generally capable of ranging to satellites with a precision of ± 10 cm or better. Although in some cases (such as the Stalas laser station at Goddard Space Flight Center in Greenbelt, Maryland, and the station at Wettzell, West Germany) ranging has been demonstrated to ± 3 cm, several other stations have accuracies in the decimeter range at best. The only operational lunar laser ranging data has come from McDonald Observatory at Fort Davis, Texas, although scattered returns have been obtained by several other stations.

Fixed VLBI systems are under development in the United States by NASA and NGS. Other countries are also involved in VLBI development; for example, Sweden, West Germany, the United Kingdom, Canada, Brazil, Australia, and Japan.

Tests in the United States of a fixed VLBI network have demonstrated repeatability of baseline length measurements over continental distances of better than ± 4 cm. Improvements to the U.S. network are underway, and tests in early 1979 are expected to show repeatability to a few centimeters. In mid-1979, the U.S. VLBI network, working with VLBI stations in Sweden and West Germany, will attempt to measure the distances between these observing sites on opposite sides of the Atlantic.

A transportable data acquisition system under development jointly by NASA and the U.S. Geological Survey will make it possible to convert temporarily any large radio astronomy antenna to a geodetic VLBI facility. Following demonstration of this system in 1979, NASA plans to initiate procurement of two similar systems for use beginning in 1981 with antennas in other countries.

2.2 Mobile Systems

At present, the U.S. mobile laser and VLBI facilities include four-meter and nine-meter mobile VLBI systems at the Jet Propulsion Laboratory, mobile laser systems at the Goddard Space Flight Center, and a highly mobile satellite laser ranging system (the Transportable Laser Ranging System, or TLRS), which is under development by the University of Texas

at Austin. The plan for development of mobile systems by NASA is outlined in Figure 2.2-1. The French laser facility at San Fernando is transportable, and at least two European countries have plans or are considering construction of mobile VLBI or laser ranging systems (Finland and West Germany).

2.2.1 Moblas Laser Ranging Station

The eight Moblas systems are capable of ranging to low satellites at accuracies of ± 10 cm or better, and to Lageos with an accuracy of about ± 10 cm. This figure does not necessarily translate directly to baseline length without some degradation. The initial deployment of Moblas stations for crustal dynamics studies outside the U.S. will begin in April 1979. Moblas units are scheduled to be located in Australia, Kwajalein, American Samoa, at a site in the Indian Ocean, and possibly in Spain. Since it requires several months to move a Moblas station, it is planned either to locate them at semi-permanent sites in the United States and abroad, or else to move them infrequently (one or two times per year) at locations in the United States, Australia, and the Pacific Ocean.

2.2.2 Transportable Laser Ranging Station (TLRS)

The TLRS will be completed in late 1979, and is expected to be capable of ranging to Lageos to ± 3 cm and of visiting some 30 sites per year. Initially, through about mid-1980, TLRS will be used in the United States. After that time, it can be deployed by air transport to sites in other countries. A second TLRS is planned for design and construction and will be available in 1983.

2.2.3 VLBI

The nine-meter and four-meter VLBI systems will be refurbished starting in late 1979, and will not be available for field use until 1980. These systems will be used principally in the United States, although it is planned (beginning in 1981) to use them to extend the regional deformation measurements in the Western United States into

FIGURE 2.2-1 MOBILE SYSTEM DEVELOPMENT PLAN

1979 1980 1981 1982 1983 1984

LASER

- MOBLAS
 - COMPLETE DEVELOPMENT
 - GLOBAL DEPLOYMENT

- TLRS-1
 - COMPLETE DEVELOPMENT
 - U. S. OPERATIONS
 - GLOBAL OPERATIONS

- TLRS-2
 - PROCURE
 - GLOBAL OPERATIONS

VLBI

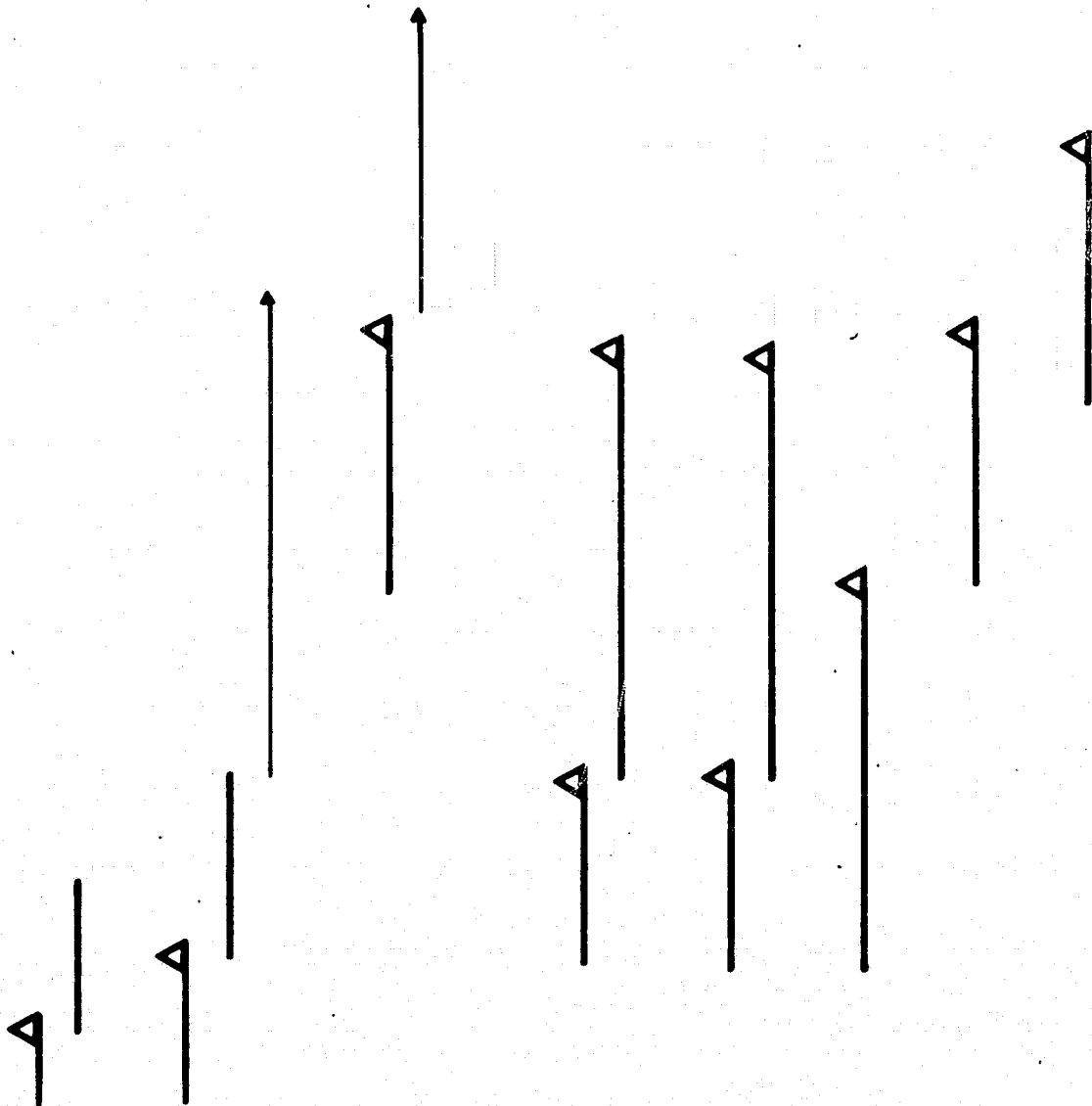
- NASA-1 (9-METER)
 - REFURBISH
 - U. S. OPERATIONS (PRIMARYLY)

- NASA-2 (4-METER)
 - REFURBISH
 - U. S. OPERATIONS (PRIMARYLY)

- NASA-3
 - PROCURE

- NASA-4
 - PROCURE

- NASA-5
 - PROCURE



Mexico and Canada, and to establish baseline measurements across active seismic areas in several other parts of the world.

Three new VLBI systems will be procured over the next several years with one of these replacing the nine-meter system. Since the NASA-initiated measurements in the United States will be assumed by the National Geodetic Survey of NOAA in 1983, four mobile VLBI systems will be available for measurements elsewhere in support of the NASA Geodynamics Program. Each of the VLBI systems, which must operate in pairs or in conjunction with a fixed VLBI observatory within 1000 to 1500 km, will be capable of visiting 20 overseas sites.

Currently, mobile VLBI has demonstrated an accuracy of ± 6 cm for baselines less than 1000 km. The new systems are expected to achieve accuracies of three to five centimeters over separations of 500 km.

2.3 Advanced Systems

Several new concepts for precise measurements of crustal deformation over distances of 20 to 200 km are being studied by NASA and by other Federal agencies. Since these systems are expected to be available in 1983 or later, they are not considered in this plan. However, for completeness, they are briefly described in the following sections.

2.3.1 Spaceborne Laser Ranging

This system uses a laser ranging instrument in a spacecraft to range to retroreflectors on the ground. A large number of these inexpensive retroreflectors would be deployed in highly active areas to obtain densification of measurements of the time history of crustal movements before, during, and after earthquakes. A single spacecraft could range to tens of thousands of retroreflectors, providing "snapshots" of positions at intervals of about three months. A country interested in participating in this program would purchase, install, and maintain the retroreflectors. Arrangements for data acquisition by foreign countries from NASA remain to be worked out. The satellite lifetime is estimated at

three years, and much longer than that if Shuttle refurbishment were used.

2.3.2 Global Positioning System (GPS)

The Global Positioning System is a DOD project that will eventually place 24 satellites in orbit for navigation and positioning.

Ground systems using doppler or interferometric methods will receive and process GPS signals to determine position coordinates for geodetic purposes. These systems will be highly mobile, and could be used to visit several sites per day. A number of systems and operating crews will be required to cover a large area within a reasonable time for the measurements to represent a static picture or snapshot of the crustal deformation taking place. To use these systems, other countries would have to purchase units in the quantities desired, and to train crews in their operation.

3.0 Basis for an International Program

3.1 Primary Areas of Interest to the United States

As described in the Geodynamics Program Plans (see references), there are both global and regional objectives of the program. The global objectives include mapping the earth's gravity field, monitoring polar motion and variations in the earth's rotation rate, and monitoring the relative movement of tectonic plates. Gravity field mapping will involve analysis of existing satellite data and the proposed Gravsat satellite mission. Measurement of polar motion, earth rotation, and tectonic plate movement will depend on a worldwide network of fixed laser ranging and VLBI observatories, most of which will be operated by other countries and in the United States by NGS (Polaris).

NASA activities will concentrate on regional-scale measurement of crustal deformation using mobile laser ranging and VLBI stations. The major thrust will be to support geodetic studies being conducted by the U.S. Geological Survey and the National Geodetic Survey in

the western part of North America. The overall objective is to understand the way the North American and Pacific plates are interacting in this area, in order to be able to predict (and possibly eventually to control) earthquake occurrence.

It is not possible to accomplish this objective by studying only one example of one type of plate boundary. Other types of boundaries, and several examples of each type, must be studied in detail.

The NASA Geodynamics Program Plan discusses the situation, and the rationale for selecting New Zealand, Alaska and the Aleutians, Andean South America, the Caribbean area, and the Fiji-New Caledonia area for intensive study. It is expected that the European Space Agency Geodynamics Program will make measurements of crustal movements in the Mediterranean region and in the Middle East.

For monitoring tectonic plate motion, a network for VLBI and laser ranging stations well distributed among the major tectonic plates is essential. For studies of regional crustal deformation along plate boundaries, a network of site ranging from 200 to 1000 km from the boundary is required. In addition, ground surveys of the conventional type are needed to relate movement of the space observatories to regional movements (see paragraph 4.1c).

3.2 International Scientific Interests

Formal international bodies are moving on a large scale toward establishment of a broad program of crustal dynamics studies in the 1980's. The U.S. and the countries identified in this document are participants in these international bodies (see Table 3.2-1).

The International Council of Scientific Unions (ICSU), which sponsors the present International Geodynamics Project (IGP), is considering propositions by the IGP to

TABLE 3.2International OrganizationsInternational Geodynamics Project

Sponsored by Inter-Union Commission Geodynamics,
International Council of Scientific Unions (ICSU).
Major components: International Union of Geodesy
and Geophysics (IUGG) and International Union of
Geological Sciences (IUGS).

Commission President: A. L. Hales (Australia).

U.S. National Committee: J. Maxwell (Texas),
Chairman.

Commission on Recent Crustal Movements

Sponsored by International Association of Geodesy, part
of IUGG.

President: Yu. D. Boulanger (USSR).

Working Group on Instruments and Methods: P. L. Bender
(Colorado), Chairman.

South American Subcommission: L. Ocola (IGP, Peru),
Chairman.

Caribbean Subcommission: A. Fonseca (Venezuela),
Chairman.

North American Subcommission: S. Holdahl (NGS), Chairman.

Pan-American Institute of History and Geography

Standing agreements among Pan-American countries on
mapping, geosciences programs.

Interamerican Geodetic Survey

Part of the Defense Mapping Agency, with headquarters
in Panama. Cooperative programs in geodesy and mapping
in Pan-American countries.

Project MERIT (Monitoring Earth Rotation by VLBI)

Sponsored by International Astronomical Union under a
working group of Commissions 19 and 31. Members
include U.S. representatives of NGS, NASA, and
universities.

extend and broaden its mandate. The U.S. National Committee for the IGP, under the National Research Council, is preparing the U.S. input to the international draft plan. The potential application of NASA-developed technology is expected to be included by the USNC/IGP. However, the international aspects of the NASA program plan will probably not be discussed by USNC/IGP. The informal discussions which have taken place between NASA and scientists of other countries may have been useful in encouraging other countries (through their scientific leadership) to propose joint programs with the U.S. as part of their contribution to the ICSU-sponsored studies.

The ICSU activity is mainly an information exchange between active research groups in different countries. It is nevertheless important since it can be a strong catalyst for the unified global program needed to address the important scientific issues. It is also important to scientists in countries who wish to develop joint programs with external colleagues, since it offers a forum through which possible arrangements can be discussed. Finally, it is important to NASA, because its activities raise the level of awareness of the NASA program, both in the U.S. and in other countries.

The Pan-American Institute of History and Geography (PAIGH) is more of an operating entity than IGP. A number of agreements exist between different Pan-American countries for cooperation in a variety of fields of research. Present indications are that joint programs with Latin American countries might be most easily arranged through PAIGH.

A third important international organization is the Commission on Recent Crustal Movements, part of the international Association of Geodesy (one of the constituent Associations of the International Union of Geodesy and Geophysics, which is a member of ICSU). A vigorous collection of working groups and subcommissions of CRCM

exists, and includes leaders of geodetic and geophysical sciences in Latin America, the U.S., the USSR, and elsewhere.

3.3 Cooperative Arrangements

Arrangements between NASA and other countries will be undertaken in accordance with normal policies and practices for projects with other countries. Two general types of cooperative arrangements are envisaged:

a. Exchange of "space" (laser, VLBI, etc.) data and the opportunity to associate with the crustal dynamics program for "ground" (gravimetric and geodetic) data, as well as temporary hosting and support of NASA-operated mobile facilities.

b. Exchange of NASA-acquired "space" and "ground" data for similar data acquired by foreign observatories. In order to encourage other countries not already having such facilities to establish and operate them (a crucial factor in a long-term global crustal dynamics program), NASA plans to offer appropriate technical assistance as well as the temporary use of NASA's mobile facilities while permanent foreign observatories are being established.

In arranging for cooperative crustal dynamics projects with other countries, NASA plans to use the following guidelines:

a. Our proposed projects will encourage foreign agencies to contribute as much of their own resources as is possible to the arrangement.

b. No exchange of funds will take place between cooperating agencies as each manages and conducts its portion of the agreed effort.

c. Data and results will be openly available. This includes both NASA and foreign-acquired "space" and "ground" data which will be made available both to the participants and (upon request) at nominal cost to the international

scientific community, regardless of the existence of cooperative projects, as is the standard NASA practice. In order to make the acquired data available, NASA plans to utilize the National Space Sciences Data Center (NSSDC) at Goddard Space Flight Center, or equivalent geodetic data archives operated by other agencies. We will encourage other countries to utilize the NSSDC or to establish similar archives.

4.0 Implementation

4.1 Approach

Implementation of the international program for crustal dynamics studies will be pursued at several levels:

a. NASA will work with fixed VLBI and laser ranging observatories in other countries on scientific data exchange basis, in order to form a single worldwide network to monitor polar motion, earth rotation, and tectonic plate movement. Initially this cooperation will be arranged on a case-by-case basis. Later, as the global program becomes established, more comprehensive arrangements will be undertaken with the countries involved.

b. NASA plans to undertake cooperative projects with specified countries in areas of mutual interest where a high degree of seismic and tectonic activity is found. For the determination of crustal deformation, NASA will periodically measure the position of selected points in these areas using mobile VLBI or laser ranging stations. The host country will help select the site locations and will provide logistic support for the mobile stations, as well as detailed local gravimetric and geodetic surveys. In cases where NASA mobile observatories are temporarily stationed in other countries, these facilities would normally be operated by U.S. crews. However, where the observatories would remain abroad for extended periods, we would plan to arrange for operation by either local personnel or at the expense of the host country.

c. NASA will make arrangements for extensive regional deformation studies where plate boundaries are similar to the North America-Pacific boundary in the San Andreas Fault Zone and at subduction boundaries. Generally the same arrangements as for (a) above will apply.

NASA has made wide distribution of its draft Geodynamics Plan, and the comments and suggestions received from many countries have been incorporated into the final plan, which is now being printed. Workshops have been held in Stanford, California (1977), Boulder, Colorado (1977), Lima, Peru (1978), and by the European Space Agency at Schloss Elmau, West Germany (1978), and further workshops are planned at which the global geodynamics programs will be discussed. Presentations have been made by NASA personnel to advisory committees of NASA and of the National Research Council, and to various committees and commissions of international organizations such as IUGG and the International Astronomical Union, as well as to groups of interested scientists in many countries. The NASA program is now in a gestation period, during which these new ideas are being evaluated and absorbed by scientists in other agencies and in other countries. Position papers are being prepared by those outside NASA, describing specific propositions for cooperative work in geodynamics. These will be studied and evaluated by responsible government agencies, and arrangements with NASA will be worked out preparatory to beginning the international observational program.

4.2 Countries Involved

Based on our scientific priorities, the key countries or areas with whom arrangements should be pursued are:

- a. Australia
- b. Canada
- c. Mexico
- d. New Zealand
- e. Japan
- f. A consortium of countries bordering the Caribbean
- h. A consortium of countries in Andean South America
- i. The governments of Fiji and New Caledonia.

TABLE 4.2-1Proposed Major Activity by Country

<u>Country</u>	<u>Study Objective</u>	<u>Deployment Requirements</u>
Australia	Australian Plate Deformation. Pacific/Australian Plate Motion.	Deploy Moblas in 1979.
Canada	North American Plate Deformation.	Deploy mobile VLBI in 1981.
Mexico	North American Regional Deformation.	Deploy mobile VLBI in 1981.
New Zealand	Establish Baseline. Regional Deformation.	Deploy mobile units in 1981. Deploy mobile VLBI in 1983.
Japan	Polar Motion, Plate Motion Experiments.	VLBI experiments in 1983.
Caribbean	Regional Deformation and Plate Motion.	Deploy TLRS in late 1980.
South America	Regional Deformation.	Deploy mobile units in 1983.
Fiji Islands, New Caledonia	Pacific-Australian Plate.	Deploy mobile units in 1983.

Outlines of proposed approaches for establishing joint programs with these countries and others have been developed (see Appendix 1). These concepts are based on informal discussions with scientific groups and with interested individual foreign scientists. A summary of the major activities by country is given in Table 4.2-1. Outlines for several other countries (India, USSR, and the People's Republic of China) are given in the Appendix; however, because of uncertainties as to the practicality of arrangements, these countries are not discussed further here.

NGS and several universities have had correspondence with Dr. Yeh Shu-Hua, Director of Shanghai Observatory, and a group of scientists from that institution will visit observatories and other facilities in the spring of 1979. PRC is considering building a three-station network of fixed VLBI observatories near Shanghai, Kunming, and Urumchi to study polar motion, earth rotation, and to serve as the base network for geodetic measurements using mobile facilities.

4.3 Implementation Schedule

A schedule of events leading to arrangements for joint programs is provided in Table 4.3-1. These events and other specific activities leading to implementation are discussed below for each country or region.

4.3.1 Australia

A Moblas facility will be deployed to a site near Perth in May 1979. Arrangements are being discussed for operation of this Moblas by Australian nationals, paid for by NASA.

In the program outlined for Australia, this Moblas is to periodically visit three other locations selected in coordination with Australian scientists. This Moblas, the SAO laser, and the Australian Lunar Laser Ranging Station at Orroral Valley will be part of the joint NASA/Australian program for plate deformation and plate motion

TABLE 4.3-1
SCHEDULE OF EVENTS

	CALENDAR YEAR				
	1979	1980	1981	1982	1983
AUSTRALIA					
● PRELIMINARY PLAN	○				
● JOINT AGREEMENT		○			
● INITIATE MEASUREMENTS			○		
CANADA					
● CANADIAN PLAN	○				
● JOINT AGREEMENT		○			
● INITIATE MEASUREMENTS			○		
MEXICO					
● REQUEST THROUGH USGS		○			
● NEGOTIATE AGREEMENT			○		
● INITIATE MEASUREMENTS				○	
JAPAN					
● GROUP STUDY DISCUSSION	○				
● U. S. PROPOSAL	○				
● JOINT AGREEMENT		○			
● VLBI EXPERIMENTS					○
NEW ZEALAND					
● NEW ZEALAND PLAN		○			
● JOINT AGREEMENT			○		
● INITIATE MEASUREMENTS				○	
CARIBBEAN					
● CRCM STUDY GROUP	○				
● PRELIMINARY PLAN		○			
● REQUEST U. S. VISIT (BY COUNTRY)			○		
● INITIATE MEASUREMENTS				○	
EUROPE					
● LAGEOS SELECTION	○				
● ESA PLAN		○			
● NASA/ESA DISCUSSION			○		
● JOINT AGREEMENT				○	
SOUTH AMERICA					
● PRELIMINARY PLAN			○		
● JOINT AGREEMENTS				○	
● INITIATE MEASUREMENTS					○

studies. The first step is to develop a preliminary plan with Australian agencies. This plan will be the basis of a formal agreement.

4.3.2 Canada

Canadian scientists are interested in having a NASA mobile station visit several sites in Canada, primarily to monitor vertical movements within the Canadian Shield. These sites will also serve to monitor the horizontal stability of the North American Plate. The Canadian scientists are studying the feasibility of this project, and we expect that they will prepare a plan for such activity. We will review the Canadian plan in mid-1979, and we expect that the result of this review will form the basis for a joint program.

4.3.3 Mexico

Regional deformation measurements in Mexico are a key part of the North American regional deformation studies. Initiation of these measurements in 1981 are crucial to the NASA program.

The U.S. Geological Survey is considering the broadening of an existing agreement with the Mexican Government covering disaster relief programs; the broadening would allow joint research programs related to earthquake prediction. The simplest approach for NASA for a cooperative program may be to conduct it as part of the USGS-Mexican agreement (consistent with NASA's own cooperative project guidelines).

4.3.4 Japan

Discussions on study interests were held at meetings of the NASA-Japan Study Group in December 1978, and March 1979. Highest priority was assigned to VLBI experiments involving the radio telescope at Kashima, working together with US-operated antennas in the U.S. and Australia. The schedule calls for these experiments to begin in 1983. Other study interests proposed by NASA include: (1) use of mobile VLBI facilities on islands near Japan, working

with the Kashima facility to measure motion of Japan with respect to the Pacific and Philippine plates; (2) measurement of crustal deformation in Japan by means of NASA-operated mobile laser ranging or VLBI facilities working with Kashima or the laser ranging observatory at Dodaira. These proposals will be discussed at future meetings of the Study Group.

4.3.5 New Zealand

New Zealand scientists have reviewed the draft geodynamics program plan, and are formulating their reaction to the possibility of a cooperative program in New Zealand. A program plan will be worked out in 1979.

4.3.6 The Caribbean Region

Discussions between NASA scientists and local scientists were held in August 1978 during an IUGG symposium in Caracas, Venezuela. The Chairman of the Caribbean Subcommittee of the IUGG/IAG Commission on Recent Crustal Movements is coordinating discussions among possible participants in the program, and his plan will be reviewed in 1979.

4.3.7 Europe

The European Space Agency has established a formal body to develop a program for earth dynamics. The first meetings of the working group are taking place at the present time. It is anticipated that NASA and ESA representatives will attend each others' coordinating committee meetings as the respective programs develop. At present, NASA is assuming that all observations in Europe and the Middle East will be carried out under ESA auspices.

Proposals have been received through ESA and from individual scientists in response to the Announcement of

Opportunity for participation in Lageos laser ranging investigations. As a consequence of these investigations, it is anticipated that joint agreements for laser operations in Europe will be developed.

After the ESA geodynamics plan is formulated, joint discussions between ESA and NASA will be initiated to merge the NASA and ESA plans as parts of a global research program.

4.3.8 South America

A workshop was held in Lima, Peru in August 1978, attended by representatives of several Andean South American countries. The workshop adopted several resolutions, which were carried by participants back to government agencies and ministries in the individual countries for analysis and discussion. A second workshop or discussion meeting will be held in 1979, and plans for cooperative activities should be formulated by late 1979. We expect that operations in this area will be coordinated by PAIGH with the participation of the regional seismological organization (Ceresis) headquartered at the Instituto de Geofisico del Peru.

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Application of Space Technology to Crustal Dynamics
and Earthquake Research: NASA Headquarters, Washington,
D.C., May 1979.

The Coordinated Federal Program for the Application of
Space Technology to Crustal Dynamics and Earthquake
Research: NASA Headquarters, Washington, D.C.,
January 1979.

Appendix 1Status and Prospects for International Cooperation
with Certain CountriesAustralia

1. Purpose: Determine deformation of the Australian Plate. Determine motion of the Australian Plate relative to the Pacific Plate and the Eurasian Plate.
2. Facilities: Australian Lunar Laser at Orroral Valley. SAO laser and Moblas (four sites). DSN VLBI at Tidbinbilla.
3. NASA Responsibility:
 - Turn over custody of SAO laser to Australia.
 - Loan Moblas unit.
 - Coordinate observations.
 - Process space data and provide to host country.
 - Provide gravimeter.
4. Australian Responsibility:
 - Operate laser facilities at their cost.
 - Acquire needed ground data. Process and analyze data.
5. Approach: Develop plan with local scientists.
 - Coordinate with CSIRO and DOS.
 - (Possibly incorporate agreements in existing DSN MOU).
6. Time Scale: Initiate in 1980 and continue to 1985, with option to extend to 1990.
7. Next Action: Australian scientists are reviewing the draft Geodynamics Plan and formulaing their own program. Contact to be reviewed in spring 1979.

Canada

1. Purpose: Extend U.S. studies of North American central shield area to monitor plate deformation. Monitor regional deformation in western Canada to augment U.S. studies.
2. Facilities: Fixed VLBI stations at Penticton and Algonquin (Canadian).
Mobile VLBI stations (U.S.).
3. NASA Responsibility:
Coordinate fixed VLBI observations; acquire mobile VLBI data; and process the fixed/mobile VLBI data.
4. Canadian Responsibility:
Operate fixed stations; acquire ground data. Provide data to U.S. and other participants.
5. Approach: Work with Earth Physics Branch, EMR, to develop plan and select candidate sites for mobile units.
6. Time Scale: Initiate fixed-site cooperation in 1980, mobile observations in 1981; extending to 1986.
7. Next action: Canadian Earth Physics Branch (Department of Energy, Mines, and Resources) personnel are reviewing draft Geodynamics Plan and preparing a position paper for their Minister. Next contact in winter of 1978-1979.

Caribbean (Venezuela, Colombia, Mexico, Central American countries).

1. **Purpose:** Determine regional deformation in the Caribbean and Central America.
Measure relative motion of Caribbean plate.
Establish existence and boundaries of platelets.
2. **Facilities:** TLRS
VLBI Radio Astronomy Antenna at Los Canos, P.R.
3. **NASA Responsibility:**
Acquire TLRS measurements twice per year at each site. Process data and provide to host countries.
4. **Caribbean countries responsibility:**
Provide site logistics and ground measurements.
5. **Approach:** Use Pan American Institute of History and Geography, InterAmerican Geodetic Survey, and CRCM to develop plan with Caribbean scientists; University of Texas to operate TLRS.
6. **Time Scale:** Initiate in late 1980 and continue to 1985 with options to extend at two-year intervals to 1990.
7. **Next action:** Venezuelan and Colombian geoscientists are reviewing the draft Geodynamics Plan. CRCM coordinator for this region (Dr. Fonseca) is organizing study groups. Review in San Juan, Argentina, in October 1979.

Europe

1. Purpose: Monitor regional deformation in tectonically active areas. Determine motion of Eurasian plate relative to Arabian, African, North American plates.
2. Facilities: Satellite lasers in the Netherlands, Spain, Germany, Switzerland, Greece; Lunar Laser in Germany; VLBI stations in Sweden, England, and West Germany. Moblas and VLBI (DSN) in Madrid.
3. NASA Responsibility:
 - Help develop European plan and sites.
 - Provide (initially) tracking data for satellite and lunar ranging.
 - Coordinate observations with U.S. and other countries.
 - Process VLBI data.
 - Provide space data to European participants.
4. European Responsibility:
 - Develop plan, select sites, acquire ground data. Acquire, process, and analyze data.
 - Provide data to U.S. and other participants.
5. Approach:
 - Assist European scientists and ESA advisory groups to formulate European plan.
 - Encourage the coordination of European laser and VLBI activity through data and technology interchange.
 - Develop cooperative relationship with ESA as focal point.
6. Time Scale: Initiate in 1980 and continue to 1985, option to extend for five-year intervals.
7. Next action: ESA to form Earth Science Working Group and formulate budget request for geodynamics. ESA will invite NASA representation on coordinating committee.

India

1. **Purpose:** Determine relative motion of the Indian Plate with respect to other tectonic plates; monitor crustal deformation.
2. **Facilities:** Mobile VLBI stations; possible fixed observatories.
3. **NASA Responsibility:**
 - Provide mobile stations.
 - Assist in development of fixed observatories.
 - Process space data and provide to host country.
4. **Indian Responsibility:**
 - Acquire ground data.
 - Site selection.
 - Construct and operate fixed observatories.
5. **Approach:** Discussion with Department of Space and the Survey of India on possible cooperative programs.
Develop program with Indian scientists.
6. **Time Scale:** Discussion at IUGG meeting in December 1979.
Mobile station operations in 1982-84 time period.
7. **Next action:** Response of Indians to review of draft Geodynamics Plan.

Japan

1. Purpose: Measure relative motion of Japan relative to other plates.
Determine deformation in Japan.
2. Facilities: The Kashima VLBI Observatory in Japan.
Lunar/satellite laser ranging station at Dodaira.
TLRS
3. NASA Responsibility:
Assist in design of VLBI observatory.
Assist in bringing laser ranging observatory to operational status.
Compute orbit predictions for satellites.
Operate TLRS at mobile sites.
Process space data and provide to host country.
4. Japanese Responsibility:
Configure Kashima Observatory for VLBI experiments with US-operated antennas.
Operate fixed observatories.
Provide logistics for TLRS.
Select sites.
Acquire and process ground data.
Provide data to U.S. and other participants.
5. Approach: Discuss plans in NASA-Japan Study Group.
Work through CRCM and NASA-Japan Agreement to develop plan.
6. Time Scale: System VLBI experiments in 1981-82, joint VLBI experiments in 1983.
Continuing to 1985 with option to extend until 1990.
7. Next action: NASA-Japan Study Group Discussion, July 1979.

Mexico

1. Purpose: Regional deformation studies; extension of western U.S. measurements along San Andreas Fault System.
2. Facilities: Mobile laser and VLBI stations (U.S.).
3. NASA Responsibility:
Provide mobile systems. Process and provide space data to host country.
4. Mexico Responsibility:
Provide logistics for mobile systems.
Acquire and process ground data.
5. Approach: Possibly work through USGS cooperative agreement with Mexico.
6. Time Scale: Initiate mobile measurements in 1981 extending to 1986.
7. Next action: Inform Conacit through Mexican Science Counselor. Mexican activities are suspended while Dr. Lomintz (Earth Science Coordinator for Mexican National Research Council) is on sabbatical leave in England until May 1979. USGS is considering an extension of their agreement with the Mexican Government (now limited to disaster relief) to cover joint research in earthquakes studies, and NASA might most easily carryout joint work under this extended agreement.

New Zealand

1. Purpose: Monitor regional deformation across Axial Tectonic Zone and Alpine Fault for comparison with San Andreas Fault.
2. Facilities: Mobile VLBI units (U.S.).
3. NASA Responsibility:
Initiate baseline measurements.
Acquire VLBI data twice per year at each site.
Process and provide data to host country.
4. New Zealand Responsibility:
Select sites.
Acquire and process ground data.
Analyze VLBI and ground data.
5. Approach: Work through DSIR and the New Zealand National Committee for IUGG to develop New Zealand program.
Establish agreement with host country.
6. Time Scale: Baseline measurements in 1981.
Initiate regional deformation in 1983 and continue to 1986, option for New Zealand to continue using own systems and technological support from the U.S.
7. Next action: New Zealand geophysicists are reviewing the draft Geodynamics Plan and preparing a position paper on their willingness to cooperate.

South America (Brazil, Peru, Bolivia, Ecuador, Chile)

1. Purpose: Determine motion of Nazca and South American plates, relative to North America and Europe. Study regional deformation across subduction boundary along western coast of South America.
2. Facilities: Radio antenna in San Paolo, Brazil, SAO lasers in Peru and Brazil.
Mobile VLBI stations.
3. NASA Responsibility:
 - Provide portable Mark III system to convert San Paolo antenna to VLBI.
 - Transfer SAO lasers to host countries; U.S. to provide orbit data, spare parts, logistics
 - Provide space data to host countries.
 - Acquire and process VLBI data.
4. South American Responsibility:
 - Acquire and process ground data.
 - Provide logistic support for mobile VLBI.
 - Analyze data.
5. Approach: Work through CERESIS (Giesecke) IAGS, and PAIGH to develop plan.
6. Time Scale: Transfer SAO lasers in 1981, start fixed VLBI observations in 1981, start regional studies in 1983; extend to 1986.
7. Next action: South American geophysicists are reviewing draft Geodynamics Plan. Follow-up workshop extending August 1978 meeting (Lima) to be held October 1979 in San Juan, Argentina.

Peoples' Republic of China

1. Purpose: Determine tectonic movements in China and Tibet.
Develop observatories for participation in global network for measurement of polar motion, earth rotation, and plate motion.
2. Facilities: TLRS, mobile VLBI stations.
Chinese facilities unknown.
3. NASA Responsibility:
Assist in construction of laser ranging and VLBI observatories, and mobile stations.
Process space data and provide to host country.
4. Chinese Responsibility:
Construct and operate fixed observatories.
Acquire ground data.
Site selection.
5. Approach: Discussion in NASA-PRC study group and other PRC-US scientific cooperation study groups.
Develop plan with PRC scientists.
6. Time Scale: TBD
7. Next action: TBD

Soviet Union

1. Purpose: Study regional deformation in tectonically active areas to understand earthquake mechanisms.
Monitor global tectonic plate motion.
2. Facilities: Lunar laser (USSR).
Radio astronomy antennae.
3. NASA Responsibility:
Assist in establishing fixed VLBI stations.
Coordination of worldwide VLBI and laser network. Process VLBI data for worldwide network.
Provide space data to host country.
4. USSR Responsibility:
Operate fixed laser and VLBI stations.
Process laser data.
Provide data to U.S. and other participants.
Develop mobile station capability.
Acquire ground measurements.
5. Approach: Work through CRCM and US-USSR Study Group in Earthquake Prediction to evolve plan and roles. Activities might be coordinated through USGS or other organizations having existing agreements.
6. Time Scale: TBD
7. Next action: AN/USSR scientists are reviewing the draft Geodynamics Plan and preparing a position paper on their willingness to cooperate. Favorable response from Prof. Boulanger (head of CRCM).

Appendix 2Acronyms and Abbreviations

AN/USSR	Academy of Sciences, USSR
ARIES	Mobile Facility for VLBI
Caltech	California Institute of Technology
Ceresis	Regional Seismological Organization (South America)
CRCM	Commission on Recent Crustal Movements (IAG/IUGG)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DMA	Defense Mapping Agency
DOD	Department of Defense
DSIR	Department of Scientific and Industrial Research (New Zealand)
DSN	Deep Space Network
EDS	Environmental Data Service (NOAA)
EMR	Department of Energy, Mines, and Resources (Canada)
ESA	European Space Agency
GPS	Global Positioning System
Gravysat	Gravity Field Mapping Satellite
GSFC	Goddard Space Flight Center (NASA)
IAG	International Association of Geodesy
IAGS	Inter-American Geodetic Survey
IAU	International Astronomical Union
ICSU	International Council of Scientific Unions
IGP	International Geodynamics Project
IGP (Peru)	Instituto Geofisico del Peru
IUGG	International Union of Geodesy and Geophysics
IUGS	International Union of Geological Sciences
JPL	Jet Propulsion Laboratory (Caltech--NASA)
Lageos	Laser Geodynamics Satellite
LLR	Lunar Laser Ranging
Merit	IAU Experiment in VLBI Measurement of Polar Motion and Earth Rotation
Moblas	Transportable Laser Ranging Facility
NASA	National Aeronautics and Space Administration

NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NRC	National Research Council
NSF	National Science Foundation
NSSDC	National Space Science Data Center
PAIGH	Pan-American Institute of History and Geography
Polaris	NGS System for Determination of Polar Motion and Earth Rotation by VLBI
Ramlas	USAF Satellite Laser Ranging Station
SAO	Smithsonian Astrophysical Observatory
Series	Small Highly Mobile VLBI Facility Using GPS Sources
SLR	Satellite Laser Ranging
Stalas	Satellite Laser Ranging Station at GSFC
TDB	To Be Determined
TLRS	Transportable Laser Ranging Station
USGS	U.S. Geological Survey
USNC	U.S. National Committee
VLBI	Very Long Baseline Interferometry